Functional Near-Infrared Spectroscopy Study on Primary Motor and Somatosensory Cortex Response to Biting and Finger Clenching

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Abstract The purpose of this study was to compare the influence of biting and finger clenching intensity on the concentration of oxygenated hemoglobin (OxyHb) in regional cerebral blood flow (rCBF) as an indicator of brain activity in the primary motor (MI) and somatosensory (SI) cortices. Functional near-infrared spectroscopy (fNIRS) was used in 8 healthy subjects. Subjects were required to do biting (bite) and finger clenching (fclench) at 20, 50 and 80% of maximum force. To minimize the effect of temporal muscle activity on the working side of the jaw, the fNIRS probes were positioned contralaterally, in the left temporal region. Activation of MI and SI cortices with bite and fclench was noted in all subjects, irrespective of the intensity of bite and fclench. A significant increase was observed in OxyHb in MI and SI between 20% and both 50 and 80% intensity. In MI cortex, OxyHb showed a significant increase between 80% and both 20 and 50% fclench intensity. The results suggest that intensity of bite and fclench influences activation levels in MI and SI. Further, an activation was more obvious with bite than fclench.

1 Introduction

Previous study suggested that appropriate masticatory and occlusal forces help maintain and enhance brain function [1]. However, the underlying neurophysiological mechanism of this phenomenon remains to be clarified.

The relationship between cerebral activity and the force levels with finger stimulation has been reported in functional near infrared spectroscopy (fNIRS) studies [2], furthermore the relationship between brain activity and the stomatognathic system has been also studied using PET [3] and ffMRI [4]. However,

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few studies have carried out a detailed investigation into the relationship between temporal brain function and occlusion and mastication using NIRS.

On the other hand, fNIRS is a powerful, non-invasive imaging system. It offers many advantages, including compact size, no need of specially-equipped facilities, the potential for real-time measurement and, especially, the ability to distinguish signals, even when there is background muscular activity.

The purpose of this study was to compare the influence of biting (bite) and finger clenching (fclench) intensity in the concentration of oxygenated hemoglobin (OxyHb) in regional cerebral blood flow (rCBF) as an indicator of brain activity in the primary motor (MI) and somatosensory (SI) cortices under conditions designed to minimize the effect of associated muscle activity using fNIRS.

2 Methods

This study was approved by the Ethics Committee of Tokyo Dental College (No.164) and was conducted in accordance with the Declaration of Helsinki (Edinburgh Revision).

Subjects consisted of 8 healthy right-handed male volunteers (age, 35.6 ± 11.1 years). Informed consent was obtained from all subjects in accordance with institutional guidelines.

A bite block equipped with a force sensor (KLC-60KA-S19; Frontier Medic, Co. LTD, Japan) was prepared to measure at the position where the right upper and lower canine cusps came into contact. Furthermore, the same force sensor was used to measure fclench at the position between the right thumb and index finger. Intensity was set at 20, 50 and 80% of maximum bite and fclench force.

fNIRS (NIRStation OMM-2001, SHIMADZU Co. LTD, Japan) was used to determine rCBF in MI and SI cortices during bite and fclench. The probes were then positioned so as to cover the areas anterior and posterior to the central sulcus according to the method of Greenberg [5]. According to Hiraba et al. [6] human ipsilateral temporal muscles become active during lateral movement. Therefore, artifacts due to temporal muscle activity on the working side of the jaw can cause serious problems. The activity of left temporal muscles was monitored by an electromyograph (BioLog DL-2000, DL-141 S&ME, Inc., Japan). In order to avoid this undesirable muscle activation, the fNIRS probe helmet was positioned contralaterally, in the left temporal region. In addition, the subjects were trained to clench without activating this muscle.

Each subject was required to perform 2 blocks of tasks: the biting task block and the finger-clenching task block. Each block consisted of 6 appropriate actions (biting or finger-clenching) at the specified intensities (20%, 50 or 80%). The intensity specified was selected at random to give a final tally of two actions at each of the 3 intensities. The subject then rested for 20 s. The subject then proceeded to the next bite or fclench task following the same 20-s rest, 20-s bite or fclench, 20-s rest pattern. This meant that each block lasted a total of 60 s.

The accuracy of the probe positions for identifying active sites in the brain was evaluated in 4 of the subjects. The probe positions were overlaid on MRI (Symphony 1.5 tesla; Simens, T1-weighted sequences, 1-mm slice) anatomical surface images of each individual using a 3-D magnetic space digitizer (FASTRAK, Polhemus, USA) and a specific software (Fusion, SHIMAZU Co. LTD, Japan).

OxyHb has been proposed as the best indicator of change in rCBF in cognitive studies with NIRS [7]. Therefore, the OxyHb data for the 10-s period commencing 10 s after commencement of bite at each intensity was averaged between all subjects. Next, a statistical analysis was performed using the paired *t*-test (SAS 9.1, SAS Institute Japan, Inc., Japan) with a level of significance $p < 0.05$.

3 Results

The portion of the probe anterior to the central sulcus was positioned over the precentral gyrus, corresponding to MI, and the portion posterior to the central sulcus was positioned over the postcentral gyrus corresponding to SI with bite and fclench. However, these activated portions during bite were superior than during fclench (Fig. 1).

A tendency toward an increase in OxyHb was observed in MI and SI with bite and fclench in all subjects, irrespective of bite intensity (Fig. 2). A significant increase was observed in OxyHb in MI and SI between 20% and both 50 and 80% bite intensity (Fig. 3. (a)). A significant increase was observed in OxyHb in MI between 80% and both 20 and 50% fclench intensity. No significant increase was observed in OxyHb in SI between all fclench intensities (Fig. 3. (b)).

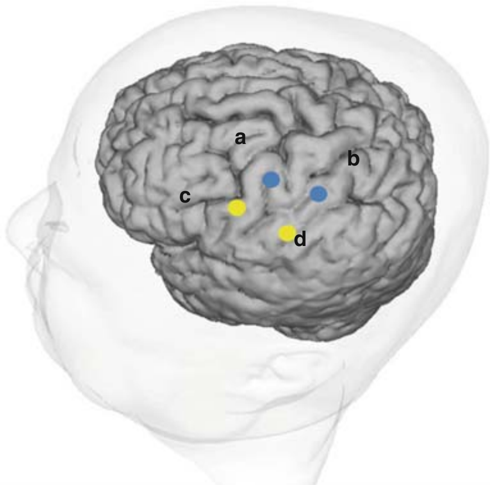

Fig. 1 Measurement positions on MRI image. (a) Primary motor cortex (MI) during finger clenching. (b) Primary somatosensory (SI) cortex during finger clenching. (c) MI during biting. (d) SI during biting

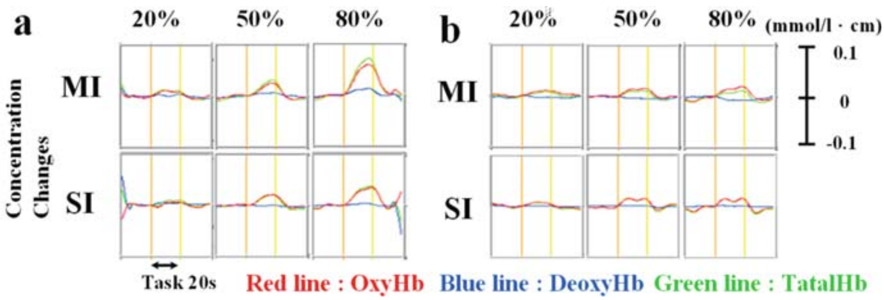

Fig. 2 rCBF changes in task. MI (*top*) and SI (*bottom*) response to biting (a) MI (*top*) and SI (*bottom*) response to finger clenching (b) A tendency toward an increase in OxyHb was observed in MI and SI with biting and finger clenching in all subjects, irrespective of intensity

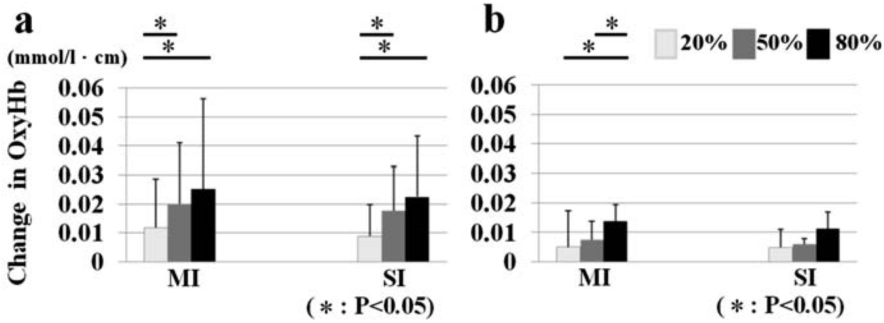

Fig. 3 Changes of OxyHb in MI and SI in response to biting. A significant increase was observed in OxyHb in the MIand SI between 20% and both 50 and 80% biting intensity (a) Changes of OxyHb in MI and SI in response to finger clenching. A significant increase was observed in OxyHb in the MIand SI between 80% and both 20 and 50% finger clenching intensity (b)

4 Discussion

The results suggest that intensity of bite and fclench influences activation levels in MI and SI. Further, an activation was more obvious with bite than fclench.

The findings of this study are consistent with those of an fMRI study by Tamura et al., in which it was found that MI and SI showed marked activation with tooth clenching and tapping. Moreover, Iwata et al. reported that the concentration chenges of totalHb at the primary hand motor area increased with the force levels [2]. This suggests that the choice of t MI and SI for measurement of brain activity in this study was appropriate.

An increased tendency toward OxyHb in the rCBF was observed contralateral to the bite side in MI and SI. This supports the findings of an fMRI study by Tamura et al. [4] which showed that the primary motor and sensory cortices exhibited remarkable activity with clenching.

Previous studies using recording of neuronal signal activity during jaw movement have suggested that many cortex neurons show movement-related activity and contribute to the control of jaw movement [8] and bite force [9]. Previous studies reported that the level of masseter muscle activity increased with hard foods [10]. Intensity of afferent-encoded information from the periodontium increases with strength of bite [11]. An increased tendency toward OxyHb in the rCBF was observed contralateral to the fclench side in the primary motor and somatosensory cortices. There are many studies using PET and fMRI clarifying a relationship between cerebral activity in the motor areas and the force levels with a tapping task [12, 13].This indicates that increase in bite intensity results in increased activity in MI.

Earlier studies on jaw movement have suggested that oral sensory information ascended into the sensory cortex, thus controlling jaw movement and discrimination of food states in monkey [14] and cat [6]. Moreover, given that there are cortico-cortical projections of the sensory cortex to the motor cortex [15, 16], it is reasonable to assume that SI information is involved in the control of biting intensity, either directly or indirectly, and that the SI region was activated in the biting task in this study. Somatosensory information not only from the periodontal ligament (predominantly via the maxillary and inferior alveolar nerve branches of the trigeminal nerve), but also from the dental pulp, gingiva, palatal mucosa, lips and skin of the jaw has been reported to increase with increase in biting intensity [17]. Therefore, with increase in bite intensity, the activity of SI increases.

Dettmers et al. found on identifiable correlation between relative rCBF and force in the primary somatosennsory cortex, and SI activation may reflect increased levels of sensory feedback with increasing peak force [12]. In addition, SI receives projections from the motor cortex. Kalaska et al. reported that SI activation highlights the intimate relationship between somatosensory and motor cortices during purposeful acts [18].

5 Conclusion

In this study, activation of MI and SI with bite and fclench was noted in all subjects, irrespective of intensity of bite and fclench. A significant increase was observed in OxyHb in MI and SI between 20% and both 50 and 80% bite intensity. In MI, OxyHb showed a significant increase between 80% and both 20 and 50% fclench intensity. The results suggest that bite elicits activation of both MI and SI and fclench elicits activation of MI. Intensity of bite and fclench influences activation levels in the brain. Further, an increasing tendency was more obvious in OxyHb with bite than fclench.

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